

Genetic Evaluation of Stillbirth in United States Holsteins Using a Sire-Maternal Grandsire Threshold Model

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ABSTRACT

A sire-maternal grandsire threshold model was used for genetic evaluation of stillbirth in US Holsteins. Calving ease and stillbirth records for herds reporting at least 10 dead calves were extracted from the Animal Improvement Programs Laboratory database. About half of the 14 million calving ease records in the database had a known livability score, mostly from herds processed by Dairy Records Management Systems (Raleigh, NC). Calf livability scores of 2 and 3, representing calves born dead and calves that died within 48 h of parturition, respectively, were combined into a single category. The model included effects of herd-year, year-season, parity-sex, sire, birth year group of sire, maternal grandsire (MGS), and birth year group of MGS. Herd-year, sire, and MGS were random effects. Mean predicted transmitting abilities, expressed as the expected percentage of stillbirths, were 7.9 and 8.6 for direct and maternal stillbirths, respectively. Mean reliabilities for both the direct and maternal effects were 45%. Correlations among domestic and Interbull stillbirth solutions on the underlying scale for bulls with at least 90% reliability ranged from 0.63 to 0.90 across countries for direct stillbirths and from 0.69 to 0.96 for maternal stillbirths, indicating that results were generally consistent with those from other countries. There was no evidence of a genetic trend for either trait. More complete recording of stillbirth scores would improve reliabilities and could allow for evaluations of other breeds.

Key words: sire-maternal grandsire model, stillbirth, threshold model

INTRODUCTION

Stillborn calves, those born dead or dying within 48 h of birth, are of increasing concern to US dairy producers. Meyer et al. (2001a) found that the still-

birth (SB) rate increased from 9.5% in 1985 to 13.2% in 1996, costing producers \$125.3 million per year. Genetic evaluations for calving ease (CE) have been computed in the United States since 1977 (Berger, 1994; Van Tassell et al., 2003), but evaluations are not provided for other traits related to calving, such as SB. Philipsson (1996) reported that about half of all stillborn calves are born without difficulty, emphasizing the desirability of separate evaluations for dystocia and SB.

Trait definitions vary slightly between countries, with most defining SB as those calves born dead or dying within 24 h of parturition (Philipsson et al., 1979), although Germany, Israel, and the United States include deaths within 48 h of birth (Weller et al., 1988; Berger et al., 1998; Interbull, 2004b). Patterson et al. (1987) found that 57.4% of preweaning losses in beef cattle under range conditions occur within 24 h postpartum, and 65.7% of all calf losses occur within 48 h of parturition. Thus, the 48-h definition has the advantage of including more perinatal losses than the 24-h definition. Breed differences play a role in perinatal mortality (Philipsson, 1976; Thompson et al., 1981), and Rossoni et al. (2005) reported that 10% of Italian Brown Swiss calves did not suckle by the third meal offered postpartum, contributing to increased postnatal mortality. Trait definitions, incidence rates, and heritabilities used by the United States and several other countries are presented in Table 1. Incidence rates and heritabilities were similar when comparing parities across countries despite differences in trait definition, with the exception of Sweden.

Berger et al. (1998) found that data were insufficient to justify the development of a routine national evaluation for SB at that time, but Meyer et al. (2001b) later demonstrated the feasibility of a linear model evaluation for SB using US data. About 3.5 million SB records were added to the national database between December 1998 and February 2006, suggesting that sufficient data for development of a national evaluation are now available (Figure 1). The purpose of this study was to determine the feasibility of implementing a routine genetic evaluation for SB in US Holsteins.

Received July 7, 2006.

Accepted November 1, 2006.

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Table 1. Properties of genetic evaluations of stillbirth in Holstein populations

Country	Parity	Definition ¹	Incidence, %	Model ²	Heritability		Reference
					Sire	Maternal	
Canada ³	All	24	8.3	ST MGS LM	0.03	0.06	Luo et al. (1999)
Denmark	1	24	9.2	MT MGS TM	0.03	0.04	Hansen et al. (2004)
Finland	1–3	24	—	MT MGS LM	0.02	0.01	Interbull (2004a)
Germany	All	48	6.8	MT AM LM	0.05	0.05	Interbull (2004b)
Holland	1	24	11.0	ST MGS LM	0.03	0.05	Interbull (2005b)
	2+		5.0		0.01	0.01	
Israel	1	48	7.4	ST MGS LM	0.01	0.01	Interbull (2005a)
Sweden	1	24	7.1	ST MGS TM	0.12	0.08	Steinbock et al. (2003)
	2		2.7		0.04	0.02	
Switzerland	All	24	—	MT AM LM	0.03	0.03	Interbull (2005c)
United States ³	1	48	11.0	ST MGS LM	0.01	0.02	Meyer et al. (2001b)
	2+		5.6		0.04	0.03	
United States	All	48	6.9	ST MGS TM	0.03	0.06	Cole et al. (2006)

¹24 = stillbirths recorded as born dead or died within 24 h of birth, 48 = stillbirths recorded as born dead or died within 48 h of birth.

²MT AM LM = multiple-trait linear animal model; MT MGS LM = multiple-trait sire-maternal grandsire linear model; ST MGS LM = single-trait sire-maternal grandsire linear model; ST MGS TM = single-trait sire-maternal grandsire threshold model. When both linear and threshold model analyses were provided in an analysis, only the threshold model results are presented.

³Evaluations were for research purposes only.

MATERIALS AND METHODS

Data

Data originated both from DHIA and from AI organizations through collection by their cooperating progeny test herds. Almost all data were originally collected through AI organizations, but over time, the portion of data collected through DHIA has increased

so that nearly all recent data were collected via DHIA and processed through dairy record processing centers, principally Dairy Records Management Systems (Raleigh, NC).

Calving ease and SB records for Holstein calvings were extracted from the Animal Improvement Programs Laboratory database and subjected to a series of data quality edits (Van Tassell et al., 2003). Herds

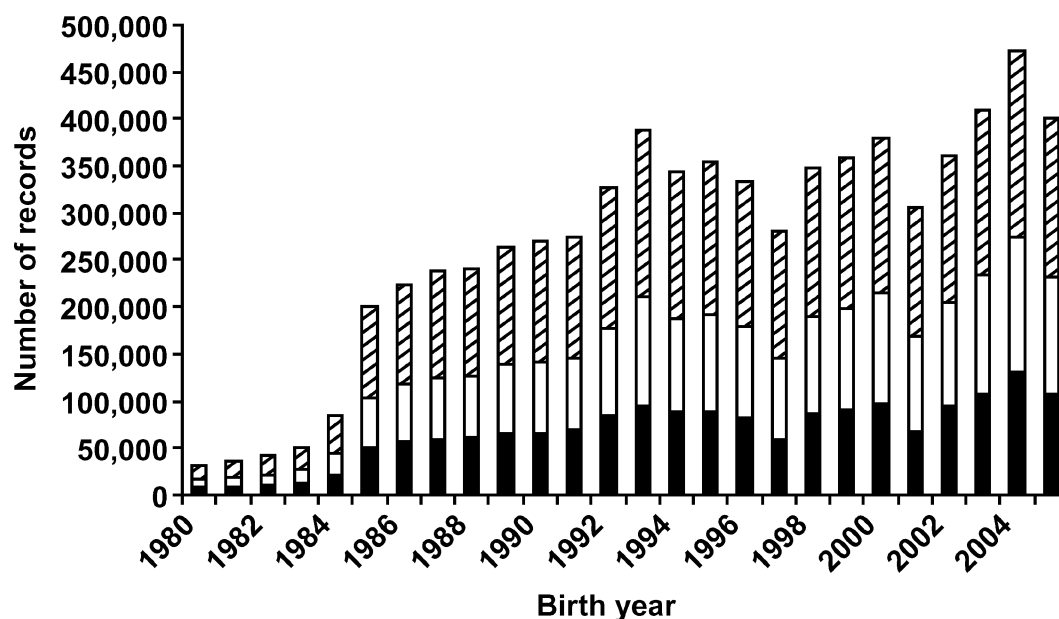


Figure 1. Number of Holstein stillbirth records in the national calving ease database with usable calf livability scores for cows in first (solid bars), second (open bars), and third and later (hatched bars) parities.

Table 2. Number of records and stillbirth rates in US dairy breeds¹

Breed	Records	Live births, %	Stillbirths, %
Ayrshire	1,800	94.5	5.5
Brown Swiss	16,910	94.1	5.9
Guernsey	1,971	92.2	7.8
Holstein	7,301,976	93.1	6.7
Jersey	36,918	94.9	5.1
Milking Shorthorn	346	95.7	4.3

¹Statistics were calculated from the national database and included all records with valid calf livability scores; no edits were applied to these data.

were required to have at least 10 calvings resulting in dead calves in the database to be included in the SB evaluation. This was done to avoid bias from herds that reported only live calves. Only data from single births were used. Calf livability is reported on a 3-point scale, with 1, 2, and 3 representing calves born alive, calves born dead, and calves that died within 48 h of parturition, respectively. A score of 0 indicates that no livability score was reported for that calving; missing observations were not included in the analysis. For evaluation, scores of 2 and 3 were combined into a single category representing stillborn calves. Only Holstein records were used because available data were insufficient to permit the evaluation of other breeds (Table 2). The SB data are a subset of the CE data; however, the entire CE pedigree file was used for the SB evaluation. Including sires and maternal grandsires (MGS) without observations produced pedigree indices instead of PTA for 2,597 bulls. The distribution of SB and CE scores in the raw and edited data sets are presented in Table 3; the edited data set included about 6 million records. A total of 135,235 bulls were represented, 44,290 of which were AI bulls from participating AI organizations.

Genetic Evaluation Model

The sire-MGS (**S-MGS**) model implemented for the routine CE genetic evaluation (Van Tassell et al., 2003) was used to analyze the SB data:

$$y = HY + YS + PS + Y_s + Y_m + s + m + e \quad [1]$$

where y is the SB score, HY is the random herd-year effect, YS is the fixed year-season effect, PS is the fixed parity-sex effect, Y_s is the fixed sire birth year effect, Y_m is the fixed MGS birth year effect, s is the random sire effect, m is the random MGS effect, and e is the random residual effect. Parities were first, second, and third and later. Year-season groups began in October and May.

The Bayesian analysis (co)variance components of Cole et al. (2007) were used: herd-year, 0.087; sire, 0.009; S-MGS, 0.018; and residual, 1.000. These components correspond to sire and S-MGS heritabilities of 0.030 and 0.065, respectively. The estimated genetic correlation of direct and maternal components was 0.002. The estimated correlation of sire and MGS components was 0.331, which includes the portion of the direct effect of the MGS also included in the S-MGS effect.

Sire and MGS solutions on the underlying scale were transformed and expressed as the expected percentage of SB (%SB). Genetic bases for sire solutions, called service sire SB (**SSB**), and MGS solutions, called daughter SB (**DSB**), were defined by groups of bulls born between 1996 and 2000 and between 1991 and 1995, respectively. Five-year averages were used to set the base because of high year-to-year volatility attributable to large effects of some sires of sons in some individual years. A base of 8% was used for both SSB and DSB.

Predicted transmitting abilities for %SB were computed similarly to those for the percentage of difficult

Table 3. Distribution of livability and calving ease scores before and after editing in the data set used for the national genetic evaluation

Calving ease score	Before editing					After editing			
	Livability score ¹					Livability score ²			
	0	1	2	3	Total	1	2	3	Total
1 = No problem	4,807,707	5,325,523	189,529	23,274	10,346,033	4,560,249	175,140	20,424	4,755,803
2 = Slight problem	908,760	609,923	59,951	2,956	1,581,590	522,073	56,090	2,534	580,697
3 = Needed assistance	772,338	455,919	83,351	3,832	1,315,440	393,940	78,559	3,347	475,846
4 = Considerable force	221,797	128,366	45,251	2,024	397,438	111,373	42,130	1,742	155,245
5 = Extreme difficulty	119,031	49,479	39,631	1,542	209,683	40,317	35,687	1,275	77,279
Total	6,829,633	6,569,210	417,713	33,628	13,850,184	5,627,952	387,606	29,322	6,044,880

¹Livability scores: 0 = no score reported, 1 = calf born alive, 2 = calf born dead, 3 = calf born alive but died within 48 h of birth. Scores of 2 and 3 were combined for evaluation.

²Records with livability scores of 0 were not included in the national evaluation.

Table 4. Distribution of livability scores by parity and sex of calf before editing in the data set used for the national genetic evaluation

Score ¹	First parity				Second parity				Third parity				Total
	Male ²		Female		Male		Female		Male		Female		
	n	%	n	%	n	%	n	%	n	%	n	%	
0	926,717	51.1	944,452	51.6	1,057,675	49.6	980,352	49.7	1,523,371	47.7	1,397,066	47.9	6,829,633
1	776,724	42.9	803,991	43.9	1,017,466	47.7	947,436	48.1	1,580,216	49.5	1,443,377	49.6	6,569,210
2	104,261	5.7	78,042	4.2	52,669	2.5	38,270	1.9	80,749	2.5	63,722	2.2	417,713
3	4,636	0.3	5,445	0.3	3,580	0.2	5,105	0.3	6,110	0.3	8,752	0.3	33,628
Total	1,812,338		1,831,930		2,131,390		1,971,163		3,190,446		2,912,917		13,850,184

¹Livability scores are: 0 = no score reported, 1 = calf born alive, 2 = calf born dead, 3 = calf born alive but died within 48 h of birth. Scores of 2 and 3 were combined for evaluation.

²Percentages sum to 100% within parity-sex groups.

births in heifers presented in Van Tassell et al. (2003) as

$$1 - \%SB^* = \overline{F(T_1 - \varepsilon^* + c)} \quad [2]$$

$$\%SB = 1 - F[-\varepsilon + F^{-1}(1 - \%SB^*) + \overline{\varepsilon^*}] \quad [3]$$

where F is the standard normal cumulative density function, F^{-1} is the inverse of the standard normal cumulative density function, T_1 is the threshold between SB scores of 1 and 2 on the observed scale, ε is the solution on the underlying scale with fixed MGS birth-year solutions added to the MGS solution, and * denotes the group of animals used to define the base. A constant, c, is used to achieve the desired base, and c in equation [2] is replaced with ε in equation [3]; ε consists of the random MGS solution plus the fixed MGS birth-year group solution.

RESULTS AND DISCUSSION

The distribution of livability scores by parity and sex of calf for the raw and edited data sets are presented in Tables 4 and 5. A total of 57% of SB calves in first and second parities were bulls, which decreased to 55% in third parity. These results are consistent with those

of Meyer et al. (2001b), who also found that male calves were more likely to be stillborn. Half of the CE records in the national database had missing calf livability scores. An additional 7% were excluded because they were from herds that reported fewer than 10 dead calves. The final data set contained 6 million records, a substantial increase from the 3.4 million records available to Berger et al. (1998).

The phenotypic trend for SB is shown in Figure 2. Stillbirths averaged 10.5 and 5.9% in heifers and cows, respectively, from 1980 to 2005. The incidence of SB increased from 11.2% in 1980 to 12.0% in 2004 for heifers, and decreased from 5.8% in 1980 to 5.6% in 2005 for multiparous cows. The apparent decrease in heifer SB from 12.0% in 2004 to 11.1% in 2005 may indicate that not all records from 2005 had been forwarded to the Animal Improvement Programs Laboratory. Year-to-year variation was more pronounced in heifers than in cows. The occurrence of SB to heifers in the current study was slightly lower than that reported by Meyer et al. (2001a), 10.1 vs. 11.1% from 1985 to 1996. Stillbirths in the current data set increased from 8.6 to 10.6% in heifers and from 4.8 to 5.9% in cows from 1985 to 1996. The change in heifer SB was much smaller than that reported by Meyer et al. (2001a), 2 vs. 3.7% over the same time period. Those

Table 5. Distribution of livability scores by parity and sex of calf in the edited data set used for the national genetic evaluation

Score ¹	First parity				Second parity				Third parity				Total
	Male ²		Female		Male		Female		Male		Female		
	n	%	n	%	n	%	n	%	n	%	n	%	
1	698,580	87.1	715,651	90.1	871,692	94.4	808,698	95.4	1,325,081	94.4	1,208,250	94.9	5,627,952
2	99,423	12.4	74,002	9.3	48,737	5.3	34,572	4.1	73,913	5.3	56,959	4.5	387,606
3	4,139	0.5	4,898	0.6	3,130	0.3	4,425	0.5	5,174	0.3	7,556	0.6	2,931,922
Total	802,142		794,551		923,559		847,695		1,404,168		1,272,765		6,044,880

¹Stillbirth scores: 1 = calf born alive, 2 = calf born dead, 3 = calf born alive but died within 48 h of birth. Scores of 2 and 3 were combined for evaluation.

²Percentages sum to 100% within parity-sex groups.

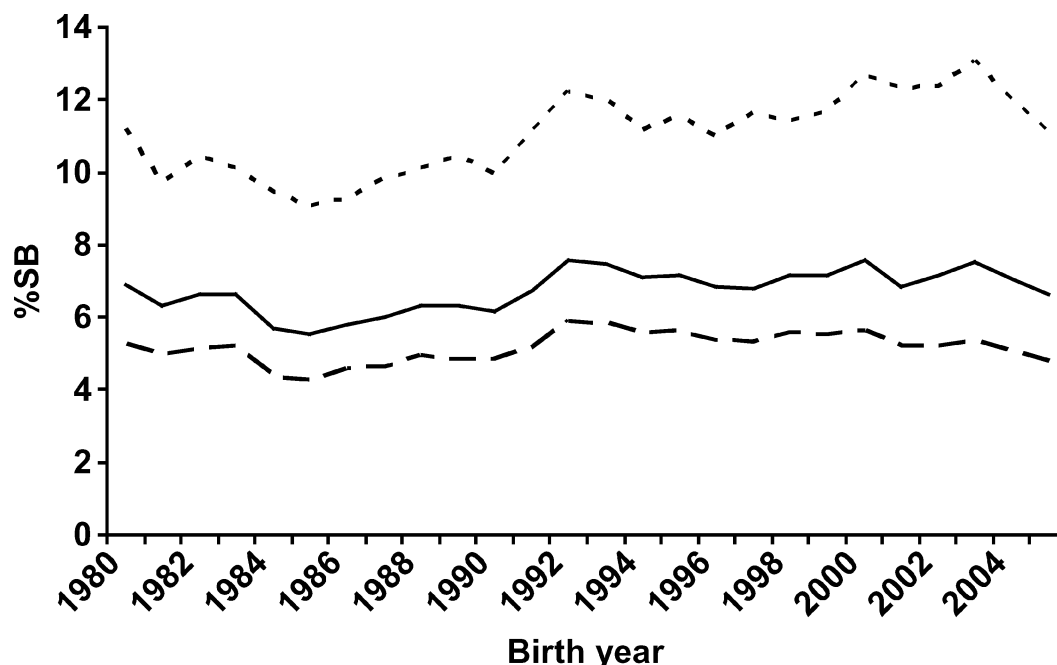


Figure 2. Phenotypic trend for stillbirths (%SB) in primiparous heifers (dotted line), cows (broken line), and all animals (solid line).

differences may be due in part to the requirement by Meyer et al. (2001a) that >90% of all calf deaths be reported in order for a herd to be included in their study, whereas reporting of ≥ 10 dead calves was required for inclusion in the current study.

Neither phenotypic nor genetic trends were significant. It is likely that the rate of increase in SB has decreased as a result of assortative mating of bulls with low PTA for CE to heifers. Correlated responses to selection for improved CE are also possible; Cole et al. (2007) estimated genetic correlations between direct CE and SB and MGS CE and SB of 0.67 and 0.63, respectively.

Statistical properties of solutions to the S-MGS model are presented in Table 6. Characteristics of the solutions were similar to results from the routine Holstein CE evaluation (Van Tassell et al., 2003). The range and SD of the herd-year solution was smaller

for SB than for CE, and was much larger than for any other effect. This lower variation reflects the fact that many more herd-years were included in the CE data than in the SB data, resulting in fewer SB herds with extreme solutions resulting from the extreme category problem (Harville and Mee, 1984; Misztal et al., 1989). The parity-sex effect was much smaller for SB than CE, 0.60 vs. 1.02, which is consistent with phenotypic trends showing that the difference between first and later parities is smaller for SB than for CE. Sire and MGS birth-year group effects were small and consistent with the lack of genetic trend for SB shown in Figure 3, which is in agreement with the report by Meyer et al. (2001b) of an unfavorable but nonsignificant trend in SSB and DSB. The increase in mean PTA for DSB in 2002 is attributable to a prominent sire of sons with extremely poor merit for DSB. Sire and MGS solutions were smaller than those for CE, and the MGS range was larger, reflecting the larger MGS variance.

When included in the model as a fixed effect, CE scores had a larger effect on SB than year-season, sire, or MGS effects (Cole et al., 2006). The magnitude of the parity-sex effect also decreased by about half, which is attributable to the increased risk of dystocia, and corresponding increased risk of SB, in heifers vs. cows. Calvings reported as requiring considerable force or being extremely difficult were more likely (1.7 and 2.3 times, respectively) to result in a stillborn calf than calvings scored as no problem. Rank correlations of

Table 6. Number of levels of effects, ranges, and SD of solutions from sire-maternal grandsire threshold model equations

Effect	Levels	Range	SD
Herd-year	73,683	3.47	0.20
Year-season	53	0.31	0.08
Parity-gender	6	0.60	0.25
Sire birth year	19	0.07	0.02
Maternal grandsire birth year	37	0.25	0.05
Sire	135,235	0.50	0.03
Maternal grandsire	135,235	0.90	0.05

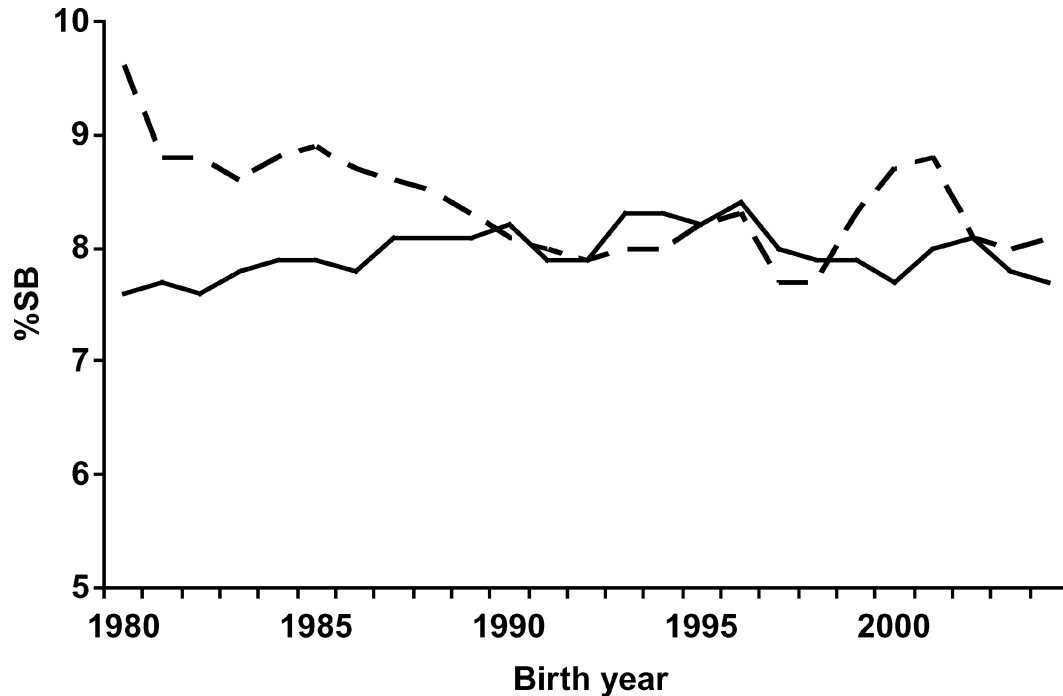


Figure 3. Mean service sire (solid line) and daughter (broken line) PTA for the percentage of stillbirths (%SB) by birth year of the bull.

solutions on the underlying scale from models with and without the effect of CE were 0.81 and 0.95 for SSB and DSB, respectively (Cole et al., 2006). Although those results indicated substantial reranking of bulls, only 3% of sires had changes of greater than 2 standard deviations on the underlying scale for SSB; only 1% of bulls had changes greater than 1 standard deviation for DSB. These findings are consistent with those of Meyer et al. (2001b), who argued for the inclusion of CE scores in models of SB to account for average differences in SB associated with different levels of dystocia.

The comparison of service sire and daughter %SB is shown in Figure 4. Mean PTA were 7.9 and 8.6% for SSB and DSB, respectively. The distribution of SSB was more compact than that of DSB, which was expected because the genetic variance of SSB is smaller than that of DSB. The correlation between SSB and DSB on both the observed and underlying scales was 0.20 for all sires ($n = 44,290$), and 0.29 for sires with reliabilities of 90% or more ($n = 951$), slightly smaller than the genetic correlation of 0.33 used in the evaluation.

Denmark, Finland, Israel, the Netherlands, and Sweden currently participate in the Interbull SB evaluation. Correlations among US SB solutions on the underlying scale with Interbull evaluations on foreign scales for bulls with at least 90% reliability in both

countries ranged from 0.63 to 0.90 for direct SB and 0.69 to 0.96 for maternal SB, indicating that results from this analysis were generally consistent with those in other countries. These ranges were similar to the range of correlations among Interbull participants. Correlations were not uniformly high because of differences in model and trait definitions among countries.

Distributions of the reliability of service sire and daughter %SB for both traits in both data sets are heavily right-skewed and reflect lower progeny numbers than are desirable from the perspective of genetic evaluation (Figure 5). This is likely because a few bulls had a large number of records available, which gave high reliabilities, but most bulls had a very small number of daughters and received correspondingly low reliabilities. In addition, Van Tassell et al. (2003) reported a consistent upward bias attributable to a simplifying assumption used in the computation of the reliabilities, that all relatives and contemporaries are perfectly evaluated, although most sires still had lower reliabilities (46 to 50%). This was more pronounced for SB than CE; most bulls had reliabilities of less than 45%, and the mode was in the 36 to 40% category. The implementation of a routine national genetic evaluation for SB is expected to show the value of reporting SB data and lead to an increase in the number of usable records collected by the National Association of Animal Breeders through the progeny test herds of

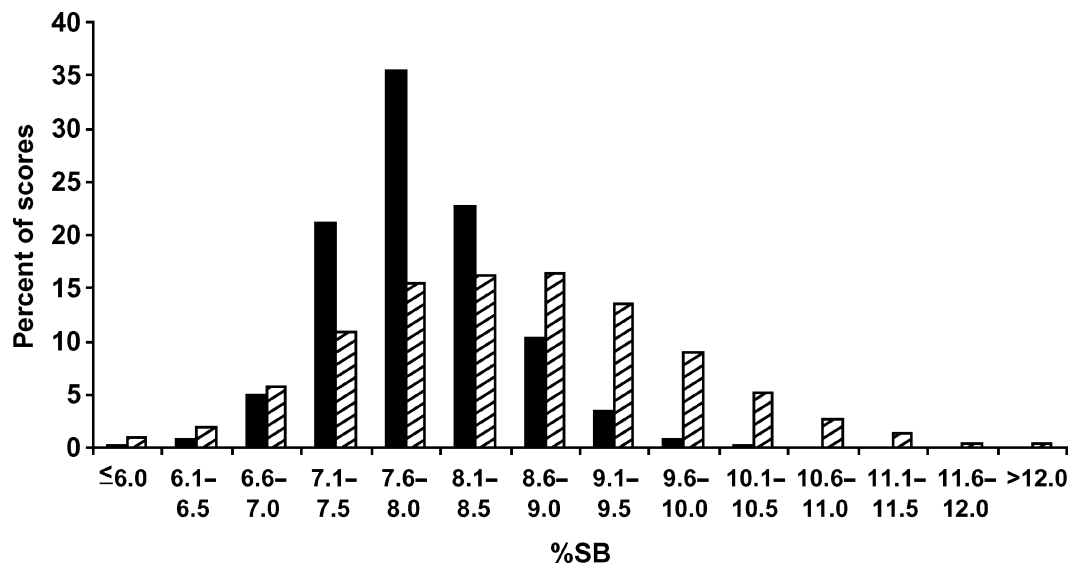


Figure 4. Distribution of all service sire (solid bars) and daughter (hatched bars) PTA for the percentage of stillbirths (%SB).

AI organizations, as well as by participants in National DHIA and other milk recording agencies. An increase in records should result in higher reliabilities for bulls.

Although Meyer et al. (2001b) made a compelling argument for including dystocia in models for SB, the model adopted for routine evaluation in the United States does not include the fixed effect of CE. There are 2 reasons for this: ease of interpretation and trait

harmonization with participants in the Interbull SB evaluation. Predicted transmitting abilities computed from a model that includes dystocia must be interpreted as the expected percentage of SB after the effect of dystocia has been removed, which presents a formidable educational challenge. Given the small magnitude of most changes in sire and MGS solutions on the underlying scale when moving from a model including

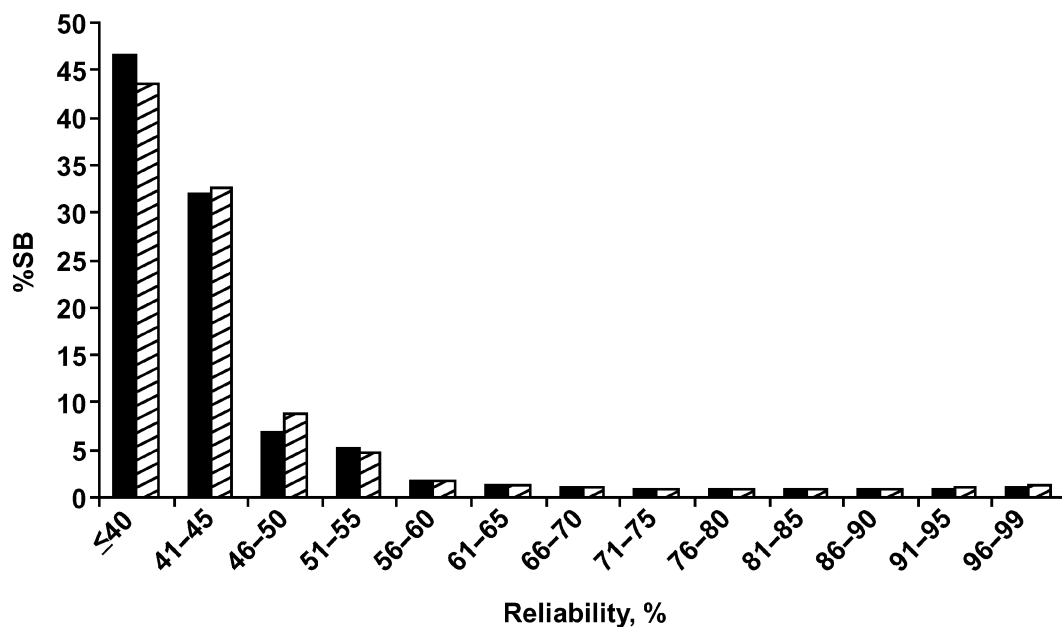


Figure 5. Distributions of reliabilities (%) for service sire (solid bars) and daughter (hatched bars) PTA for the percentage of stillbirths (%SB).

dystocia to one without, and given that reliabilities do not differ between the 2, the more parsimonious model is preferred. None of the participants in the March 2006 Interbull test evaluation for Holstein SB (Denmark, Finland, the Netherlands, Israel, and the United States) included dystocia in their SB evaluation.

Denmark (Interbull, 2003) and the Netherlands (Interbull, 2005b) use multiple-trait models that include SB in first and later parities as correlated traits, and Wiggans et al. (2006) demonstrated the feasibility of modeling parities as separate traits using a threshold model for CE in the United States. Steinbock et al. (2003) reported genetic correlations between first and later parities in Swedish Holsteins of 0.45 for SSB and 0.48 for DSB. Harbers et al. (2000) reported correlations between first and later parities of 0.52 and 0.78 for SSB and DSB, respectively, in Dutch Holsteins. Modeling first and later parities as correlated traits or including CE and SB in a multiple-trait evaluation may be more beneficial than accounting for dystocia in the current model.

CONCLUSIONS

Approximately half of the records in the national CE data set were not usable in the SB evaluation because they had missing calf livability scores. This resulted in much lower reliabilities (averaging 45%) for SB than for CE. There was no evidence of consistent phenotypic or genetic trends for SB from 1980 to 2005. An industry-wide effort is needed to improve recording for calf livability, although accuracy could be improved in the short run by development and implementation of a multiple-trait evaluation including CE and SB.

A routine evaluation for SB in US Holsteins was developed and implemented in August 2006. Direct and maternal SB were included in Lifetime Net Merit for Holsteins starting in August 2006. Domestic data from February 2006 were provided to Interbull for inclusion in the March 2006 international pilot run for CE and SB, and the United States expects to participate in routine Interbull evaluations beginning in November 2006.

ACKNOWLEDGMENTS

The authors are grateful to Jeff Berger and Kent Weigel for their valuable suggestions and discussion. Two anonymous reviewers also provided helpful feedback. John Clay and the staff of Dairy Records Management Systems (Raleigh, NC) provided invaluable assistance with the SB data. Ignacy Misztal and Shogo Tsuruta of the University of Georgia provided the CBLUP90IOD and RENUMF90 computer programs.

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